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RESEARCH ON THE DYNAMICS OF THE
SOLAR ATMOSPHERE

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Observations have been made of solar magnetic and velocity fields using the Lockheed universal filter and the Lockheed high speed video image processor. Inter-relationships between magnetic and velocity fields, fine structure of the magnetic field, and absolute magnetic field strengths were studied.

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SUMMARY

Research under this contract has produced new and, we believe, significant information about the solar magnetic field. Research has progressed in two areas - the production of combined magnetograms/velocitygrams at Lockheed, and the production of high resolution magnetograms at Sacramento Peak Observatory. These observations have shown details of magnetic structure with resolution on the order of 1/3 arc second, and have provided evidence of the existence of a weak component of the magnetic field - that is, field with a strength significantly less than that associated with network bright points. The combined velocity/magnetic field observations are still being analyzed as this report is written, and further analysis is also being carried out on the Sacramento Peak data. The observations described in this report were made using the Lockheed high-speed image processing system and the Lockheed universal filter, as well as other Lockheed equipment.

INTRODUCTION

The original contract under which the work described in this report was conducted called for the production of combined magnetograms and velocitygrams in order to investigate relationships between solar magnetic and velocity fields. These measurements were to be carried out using the high speed video image processing system developed at Lockheed. An extension to the contract specified observations at Lockheed and Sacramento Peak Observatories using the new Lockheed universal filter. Both of these observing programs have been carried out as proposed. The results of both programs will be published as soon as data reduction is complete.

Two interesting conclusions have been reached thus far as a result of photographic observations taken at Sacramento Peak. First, evidence has been obtained for the existence of magnetic fields in the solar photosphere which are significantly weaker than those normally associated with network bright points. These fields appear to be genuinely weak and not to be unresolved areas of strong field. They were observed in a series of magnetograms taken at different wavelengths across the line profile of the FeI line at 6302 Angstroms. The second result of interest is that the magnetic field is structured on a scale of the order of granular dimensions, and may be strongly influenced by velocity fields associated with granulation. This observation was made possible by the superb resolution (better than 1/3 arc second) obtained in the Sacramento Peak photographic data.

Movies were obtained at Palo Alto combining velocity and magnetic fields, with the magnetic fields color coded and superimposed on black and white velocitygrams. Two sequences have been obtained in the quiet sun, one of which superimposes the magnetic fields on a normal line-of-sight velocity-

gram, and the other of which incorporates velocitygrams showing only the slowly varying components of the velocity field, the five minute oscillation having been suppressed. These movies are still being analyzed.

DESCRIPTION OF THE APPARATUS

These observations were made with the high speed video processing system developed at Lockheed by Dr. S. Mende and Mr. E. Aamodt. The system consists of a high speed MOS shift register memory capable of storing a 256 x 256 element picture with 12 bits per element, a fast digital processor, a television camera and A/D converter, a three track video disc recorder, and a solar television monitor. The entire system can be operated under computer control, and can produce black and white or color coded output pictures. It was developed with the cooperation of Lockheed Solar Observatory for shared use for auroral studies and solar observations.

Since the system was originally configured for auroral work, it required some modification for the observations made under this contract. Specifically, it was necessary to increase the precision of the A/D converter and to modify certain signal processing circuits. It was at first believed that the only way to obtain suitable performance for solar observations was to replace the A/D converter used for auroral work with a new, more precise unit. Such a unit was requested in the original proposal. Subsequently, it was discovered that purchase of such a unit would not be necessary. The original A/D converter which had been used as a 6 bit converter for auroral studies was returned to full 8 bit resolution and the input circuitry was modified. Performance of the 8 bit unit is marginal near the limb where large variations in background intensity exist due to limb darkening, but good results can be obtained if care is taken in adjustment of the unit. Moreover, Lockheed provided a suitable high speed A/D converter with 10 bit resolution. Unfortunately, this converter was received too late for use in this year's

observations, but should be useful in follow-on studies.

The Lockheed universal filter was developed under a NASA contract as a prototype of an instrument to be used in space applications. It uses a combination of partial polaroids and achromatic wave plates to achieve good suppression of sidebands throughout its tuning range. The filter is of exceptionally high optical quality having very uniform characteristics across the aperture. It is tunable from 4500 Å to 8000 Å and has a bandpass of 1/7 Å at 6000 Å. The filter is unique in that it requires no temperature controlled oven. Rather, the computer which is used to control the wavelength to which the filter is tuned senses the temperature of each calcite element, and automatically compensates for temperature changes. The filter is tuned mechanically by means of stepper motors. The universal filter was used for the observations made at Sacramento Peak.

The observations made at Palo Alto were made with a hybrid Lyot-Fabry-Perot filter tuned to 6302 Å. This filter was more easily adapted to velocity field observations than the universal filter, and was available for observations earlier than the universal. The Palo Alto observations were made on the Lockheed large spar with a 7" aperture lens.

MAGNETOGRAM/VELOCITYGRAM OBSERVATIONS

The purpose of these observations was to display magnetic and velocity fields in a combined way so that correlations between the two could be studied. This was accomplished by color coding the magnetograms and superimposing them on intensity coded velocitygrams taken alternately with the magnetograms. The magnetogram was recorded on one track of the video disc recorder, and the velocitygram on another track. The two pictures were then combined and sent to a color television monitor in such a way as to color code the magnetogram on an orange to blue scale,

and to display the velocitygram on a black to white grey scale. An excellent sequence was taken using the 6302 Å filter on August 25, running from 10:40 PDT to 12:20 PDT with a five minute time resolution. A second sequence taken August 24, running from 11:15 PDT to 16:50 PDT, consists of a sequence taken in the quiet sun near the limb. In this case, time resolution is 15 minutes, and the velocitygrams are double-cancelled to remove the five minute oscillation. Each velocitygram consists of the sum of two velocitygrams taken 2-1/2 minutes apart.

The analysis of the two sequences described above is still underway, but a few tentative conclusions have been reached. First, magnetic bright points do seem to align themselves along supergranule velocity boundaries as might be expected. However, it appears that motions of magnetic field elements do not necessarily correlate with supergranule velocities at the time of the change. Alan Title suggests that these facts may be explained by action of granulation on the magnetic field, which could be responsible for moving field away from supergranule boundaries on time scales short with respect to supergranule lifetimes. Further analysis of this data is necessary. At least one paper will be published in the near future as a result of these studies.

The technique employed for the production of these magnetogram/velocitygram combinations offers a powerful method for comparison of related phenomena, and will be useful for future studies of a similar nature. A typical combined magnetogram/velocitygram is shown in Fig. 1

HIGH RESOLUTION MAGNETOGRAM OBSERVATIONS

Observations made at the Sacramento Peak vacuum telescope with the Lockheed universal filter have produced a number of magnetograms made at various wavelengths in the 6302 Å line with spatial resolution of 1/3 arc second or better. These magnetograms are the result of computer reduction of photo-

Figure 1. A Typical Magnetogram/Velocitygram Combination. (Note for the draft report - this picture should be supplied in color, since the magnetic fields are color coded. It will be so supplied in the final report with the approval of the monitoring agency.)

graphic observations. Additionally, magnetograms were made using the high speed video processing system and the universal filter. There was no capability at Sacramento Peak of making color coded magnetogram/velocitygram observations, although a capability for making either type of observation independently did exist with the equipment brought to Sacramento Peak. Unfortunately, due to a hurricane, only a few hours of consistent sunshine were obtained during the time spent at the peak. Since part of that time was used for setting up and testing the system, only a short time was left for observations. For this reason, only magnetic field observations were made.

Of the two types of observations, the more interesting at present are those made photographically, primarily because of their higher spatial resolution. The resolution of the electronically processed magnetograms was significantly lower due primarily to image motion during the period required to integrate the electronic subtractions. Figure 2 shows a pair of filtergrams, taken in right and left circularly polarized light, at a wavelength .04 Å to the blue side of line center in FeI 6302 Å. Figure 3 shows the photodigital magnetogram of the outlined area, produced by microdensitometering the filtergrams and digitally subtracting and processing the results. (The two images in Fig. 3 are identical, except that they have inverted gray scales.) For comparison, a typical videomagnetogram (of a different region) is shown in Fig. 4.

The magnetogram in Fig. 3 shows the fields in a strong plage area within a sunspot group. One immediately notices that the fields resolve into strands which are typically 1/2 arc second or less across (the tick marks along the bottom edge are one arc second apart). The fields are organized into a large cellular pattern quite similar to the familiar photospheric network seen in quiet areas of the disk, although these cells have only about half the diameter ($\sim$ 15000 km) of typical supergranule cells. The fields which form these large cells are in turn comprised of smaller cell-like structures of 2-3 arc second diameters, or approximately the scale of ordinary granulation.

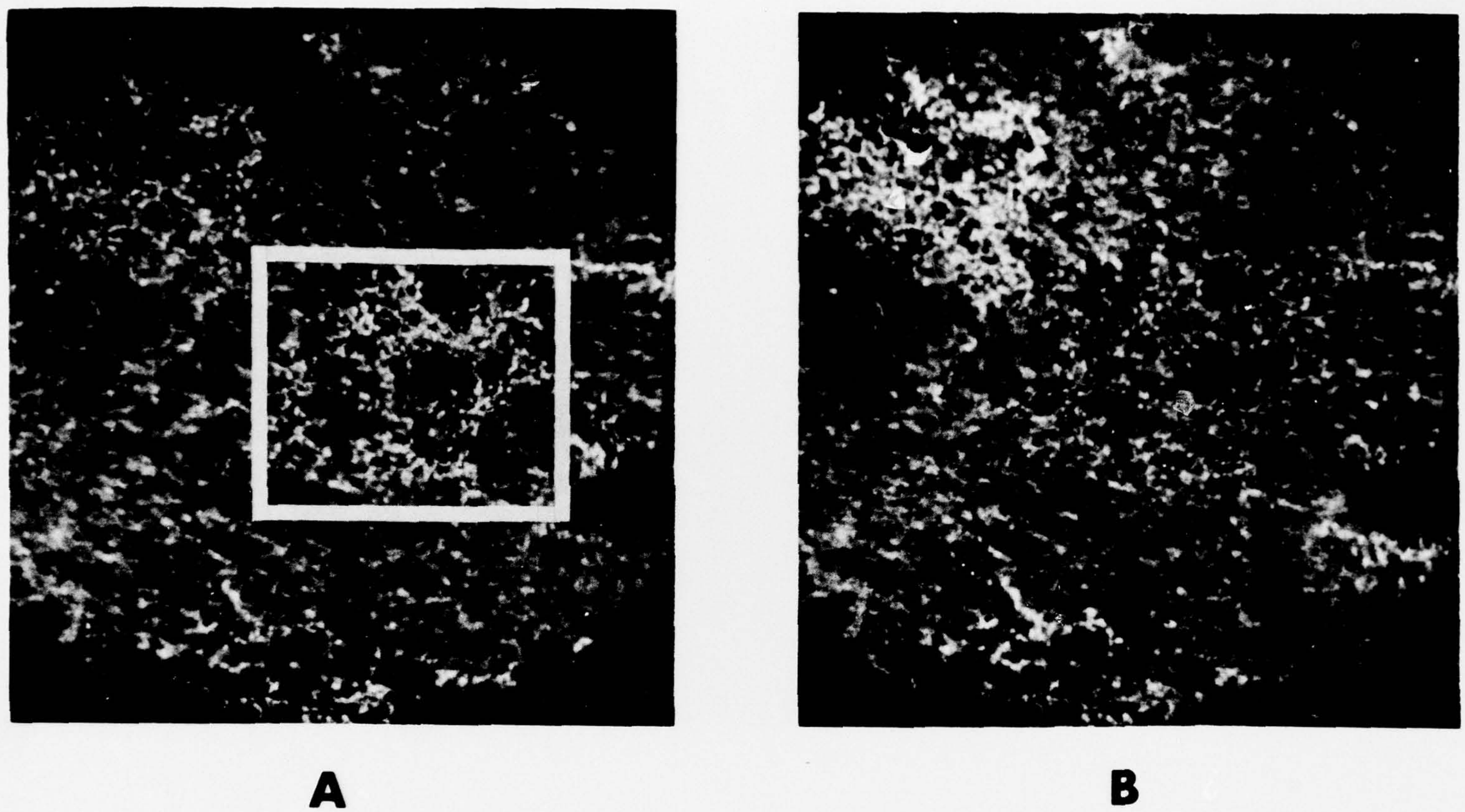

Figure 2. Filtergrams in right and left circularly polarized light at 0.04 Å to the blue side of line center of FeI 6302. The diameter of the field is 2-1/2 arc min. The white box outlines the area whose magnetogram is shown in Fig. 3.

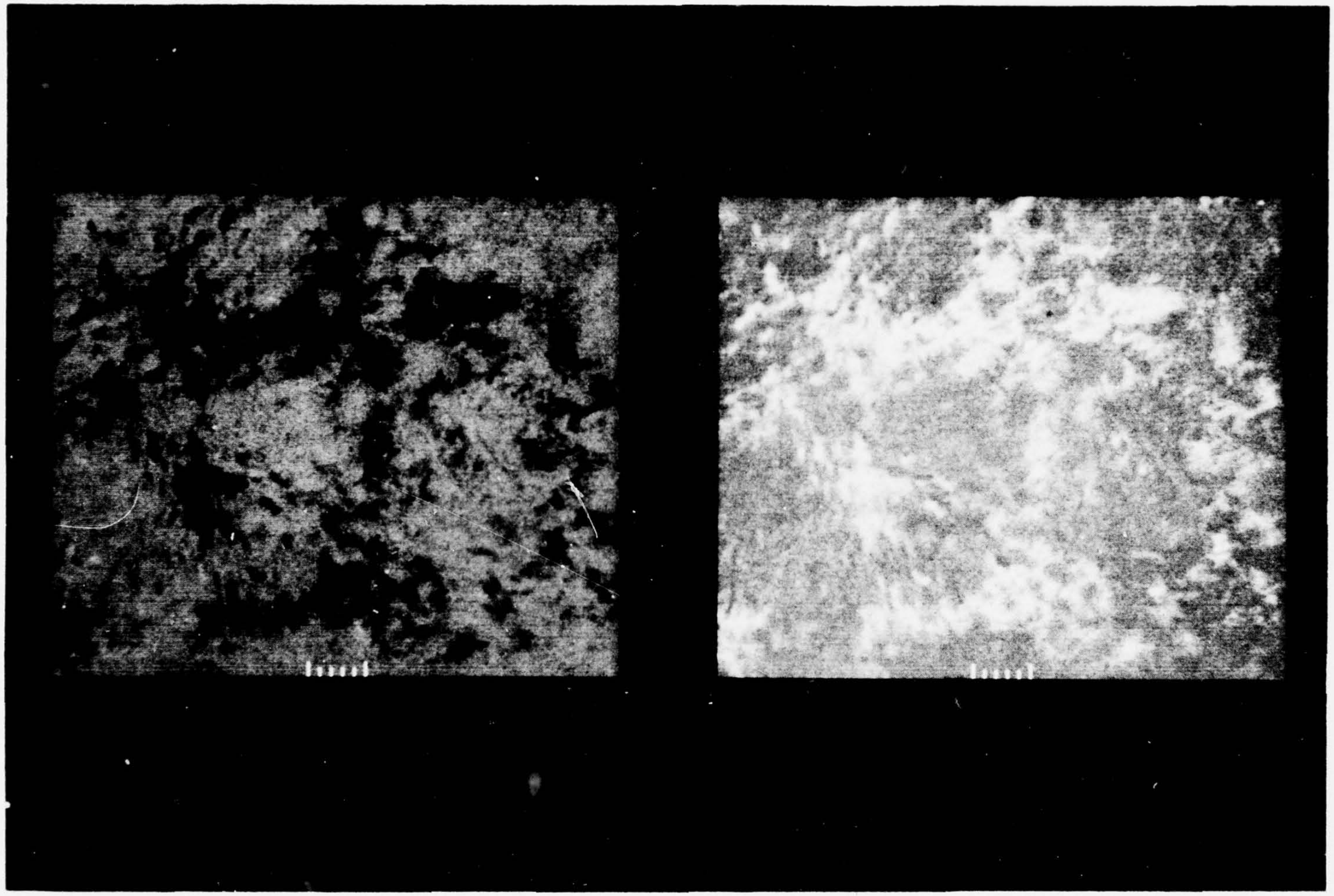

Figure 3. Photographic Magnetogram. Two renditions of the same unipolar region with fields displayed in opposite senses. Ticks are separated by

Figure 4. Video Magnetogram. The area covered is 96 x 128 arc seconds.

The magnetogram has been carefully overlaid on a filtergram taken a few seconds later in the red wing of the line and which therefore shows the granulation in high contrast due to the differential velocities between the rising granules and the falling intergranule lanes. We find that the small cells do not outline granules or coincide with intergranule lanes. Rather, the individual flux points which comprise the small cells appear to coincide with the centers of granules. These are not bright, well formed granules, however. Without exception, granules show lower than average contrast and are fragmented in appearance. This is certainly the phenomenon which Dunn and Zirker (Solar Physics 33, 281, 1973) call "abnormal granulation".

We have studied a series of these magnetograms taken at 2-1/2 minute intervals over a 10 minute span. In that period, we found two small cells which had clearly evolved. However, most of the cells had retained their basic shapes. We can thus conclude that the mean lifetime of these small cells is long compared to 10 minutes, but probably less than an hour.

Finally, it will be noticed that the area covered by the magnetogram is monopolar. There is virtually no indication of opposite magnetic polarity. This conflicts sharply with the salt-and-pepper effects which the KPNO magnetograph shows at its highest sensitivity. Although there is no magnetic calibration on the Lockheed system, we can estimate by simple signal-to-noise arguments that our threshold of detection is approximately 50 gauss averaged over our resolution element. KPNO measures the bipolar fields at the 3-5 gauss level, with a real (seeing-smeared) resolution of about 2 arc seconds. Therefore, if these were really strong, compact field elements, they ought to be clearly evident on our magnetogram. The fact that they are absent argues strongly that the background bipolar fields detected by KPNO must be weak, diffuse fields, and therefore contradicts the currently popular notion that all solar fields are 1000 gauss or greater.

A paper on this work (Schoolman, Title, and Ramsey) was presented at the recent Honolulu meeting of the Americal Astronomical Society, and a manuscript for

Astrophysical Journal Letters is in preparation.

A final result of interest came from the line scan magnetograms. These were magnetograms taken at 1/100 Å intervals across the 6302 Å line. A major purpose of these scans was to determine if there exist any magnetic field structures of different strength (rather than integrated line-of-sight component strength) from the general plage field strength. This would be the case if the apparent strength of different features were to peak at different points in the line profile, since the line splitting, and thus the wavelength of maximum signal varies as the magnetic field B, and not as the line-of-sight component of B. It was found that certain diffuse magnetic structures do, in fact, show a peak in signal strength significantly closer to line center than the peak for most magnetic bright points. This indicates a field strength for these structures significantly less than the values (around 1000 gauss) usually measured for plage fields. This problem is also being further studied. Similar line scans are being examined which were made photoelectronically, and results will be published shortly.

CONCLUSIONS

The data obtained under this program shows clearly the value of the universal filter for obtaining information from the entire profile of a Zeeman sensitive line rather than from a single wavelength. This makes possible the determination of absolute magnetic field strength as opposed to the magnetic flux or line-of-sight component integrated over the resolution element of the magnetograph. Since the magnetic field strength is usually the parameter of physical interest, the use of tunable filters will greatly enhance the significance of magnetic observations.

The usefulness of the video image processor has also been demonstrated in its ability to rapidly display in a meaningful way related phenomena such as magnetic and velocity fields. Such an instrument is not, at present, suitable for high resolution work, since the relatively long integration times required destroy any high spatial resolution which may be present. In our runs at Sacramento Peak, it was not possible to achieve high resolution even when the seeing was good throughout an observing interval. This was due to distortion of the image rather than blurring. A magnetograph equipped with a high speed correlation guider or an autoregistration routine would do much better.

The scientific results from this program will produce several papers, and, we believe, will add materially to our knowledge of the detailed structure of the solar magnetic field.

RECOMMENDATIONS

The usefulness of the universal filter has barely been scratched in this program. Further observations should be made to obtain vector magnetic fields, changes of magnetic field with height in the solar photosphere, and other observations which exploit the tunable filter. Lockheed presently intends to narrow the filter bandpass to 1/20 Å to improve vector magnetic field resolution, and to add thin elements to lessen the need for blockers.

There is a need for a comprehensive statistical study of correlations between solar small-scale magnetic field motions and photospheric velocity fields. Such studies should shed light on the basic mechanisms of magnetic flux diffusion and field generation. The video image processing system is ideally suited for such observations.

Finally, the observations already made under this study will provide material for extensive analysis. Such analysis should continue, and will produce additional detailed information concerning the solar magnetic field.

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